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ANALYTICAL AND EXPERIMENTAL INVESTIGATION ON THE MODAL PROPERTIES OF SCALED CONCRETE RETAINING WALL

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ABSTRACT:

In this study was investigated of possibility using the recorded micro tremor data on ground level as ambient vibration input excitation data for determination and application Operational Modal Analysis (OMA) for scaled concrete retaining wall. As known OMA methods (such as FDD, EFDD, SSI-UPC/SSI-PC/SSI-CVA and so on) are supposed to deal with the ambient responses. For this purpose, analytical and experimental modal analysis of a scaled concrete retaining wall for modal properties was evaluated. 3D Finite element model of the building was evaluated SAP2000 for the scaled concrete retaining wall based on the design drawing. Ambient excitation was provided from the recorded micro tremor ambient vibration data on ground level. Enhanced Frequency Domain Decomposition (EFDD) is used for the output only modal identification. From this study, very best correlation is found between mode shapes and frequencies. Natural frequencies and analytical frequencies in average (only) %2.58 are differences.

Keywords:experimental modal analysis; modal parameter; EFDD; retaining wall; concrete

INTRODUCTION

In recent years, in the world and our country, the determination of the effect of vibrations on structures and structural behavior has become very important. Our country has many important structures in terms of its historical background and geographical location. In addition, the earthquakes that have frequently occurred in recent years in our country have increased the researches and studies on the experimental determination of the behavior of structures under vibration. Many buildings built in the past are known to suffer many damages due to faults in the design and manufacturing stages, as well as natural disasters and overload effects. Especially when our country is on an active earthquake zone, we have over 80 million inhabitants, considering our geographical position; Damage assessment and assessment are clearly visible in terms of our country. Structures are under constant vibration. Many factors such as wind, earthquake, wave, explosion, and vehicle load etc. cause vibration. These vibrations sometimes cause cracks and sometimes serious damage. Thus, the determination of the behavior of structures under vibrations directly affects the life of that structure. The behavior of the structure under the vibrations affecting it can only be determined by experimental studies. At the design of the structures, firstly analytical models are formed to represent the structures and static and dynamic analyzes are carried out for different loading situations on these models. But in most cases the analytical model created does not fully represent the actual behavior of the building. The comparison of dynamic parameters is used as a practical solution in determining and eliminating differences in building behavior.

Retaining structures are elements manufactured to limit the movement of the ground under the natural slope angle. Apart from this purpose, for constructive purposes, separation of two different grounds, etc. They are used in situations. Different types of retaining structures have emerged depending on the mechanical properties of the ground. In addition to these mechanical properties, the place of use of the retaining structure to be built (coast, sea, etc.), its purpose (to ensure ground stability, to separate different soils, etc.), environmental conditions (air temperature, humidity, etc.), other nearby structures status, etc. It should be designed by considering the situations. Today, retaining walls are the most preferred retaining structures. There are many reasons why these structures are used frequently. First of all, their project is easy and fast compared to other structures. Size flexibility is unlimited compared to other building types. Many different types of materials can be used (concrete, reinforced concrete, steel, masonry, composite, etc.). They are very successful against many dynamic load types (earthquake, tsunami, blasting, etc.) apart from their main usage purposes [1].

Researchers have done a lot of work on retaining walls. Some researchers have examined different types of retaining walls under different soil properties. Retaining wall types used can be counted as gravity, piling, cantilever and anchored. It is quite a lot of researchers who examine the behavior of retaining walls using finite element method under various dynamic load effects. Most of the studies on retaining walls are analytical [2]. Therefore, it has been revealed that experimental studies should be conducted to examine such structures, which are of great importance for the stability of the ground and structures. Along with the technological developments, important steps have been taken in the experimental study of retaining walls there is a limited number of studies on operational and experimental modal analysis of retaining walls. In these studies, various types of materials (concrete, reinforced concrete, masonry, etc.), type of retaining wall (gravity, cantilever, piling, etc.), boundary conditions, etc) [3]. Examinations were made according to the parameters. Some researchers have done similar studies under different environmental conditions [4], [5], [20]. There are few studies in the literature for the operational modal analysis of concrete retaining walls. Studies [6-13] on operational and experimental modal analysis began on the basis of system identification. There are many studies on system identification [14-18]. Nowadays, researchers use genetic algorithm [19], artificial neural networks [20-24], fuzzy logic [25-26], etc. they moved the works in different directions. In the studies, the use of traditional tools and equipment has been replaced by more advanced technological materials. Wireless accelerometers, self-powered sensors, etc. are some of them. Many new technologies have been developed for the continuous monitoring of the dynamic parameters of the retaining walls. With these technologies, it has become possible to produce safer structures and to constantly control the structure. In order to reach the dynamic parameters correctly, it is necessary to define the parameters of the structure correctly. In most studies, it was observed that the finite element model of the retaining walls and the dynamic parameters obtained from the operational modal analysis were different. The differences between the finite element model and the operational modal analysis are at an acceptable level of 2-5%. In situations where there is more difference, it is frequently encountered that there are errors in the finite element model or measurement. Errors in the finite element model are often due to incorrect material properties, dimensional measurement errors, etc. It arises. Errors in measurement are deficiencies in fixing the accelerometers, environmental effects, etc. can be listed as. In this study, special attention was paid not to make mistakes in the finite element model and operational modal analysis measurement mentioned above, which was positively reflected in the results.

In general, operational modal analysis is used to determine the damage levels of the existing structures, to check the validity of the assumptions made while constructing the finite element model, to update the initial numerical model of the existing structures according to the experimental data, to determine the dynamic characteristics of the structures by the experimental modal analysis method when the numerical model of the existing structures cannot be formed and to follow the structural health is widely used in the process [6-13], [27-30].

For this purpose, analytical and experimental modal analysis of a scaled concrete retaining wall for dynamic characteristics was evaluated. 3D Finite element model of the building was evaluated for scaled concrete retaining wall based on the design drawing. Ambient excitation was provided from the recorded micro tremor ambient vibration data on ground level. Enhanced Frequency Domain Decomposition is used for the output only modal identification.

MATERIAL AND METHOD:

A. Description of scaled concrete retaining wall:

Scaled concrete retaining wall is 0.25 m height. Shape of retaining wall is rectangular prism. Dimension of element is shown in Fig. 1.

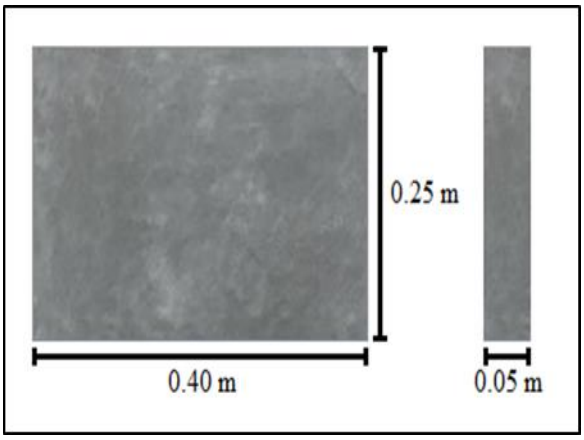


Fig. 1. Illustration of scaled concrete retaining wall (front and side view)

The Quanser shake table II is a uniaxial bench-scale shake table. This unit can be controlled by appropriate software was illustrated. It is effective for a wide variety of experiments for civil engineering structures and models. Shake table specifications are in table 1.

Table 1. Shake Table Specifications

Parameter	Units	Value
Table dimensions	cm	46x46
Weight	kg	27
Motor maximum torque	N.m	1.65
Maximum force	N	700
Maximum payload at peak acceleration	kg	15
Operational bandwidth	Hz	20
Stroke length	cm	+/- 7.5
Peak velocity	cm/sec	83.4
Peak acceleration	g	2.5
Ball screw efficiency	%	90

B. Modal parameter extractions (EFDD):

The (FDD) ambient modal identification is an extension of the Basic Frequency Domain (BFD) technique or called the Peak-Picking technique. This method uses the fact that modes can be estimated from the spectral densities calculated, in the case of a white noise input, and a lightly damped structure. It is a non-parametric technique that determines the modal parameters directly from signal processing. The FDD technique estimates the modes using a Singular Value Decomposition (SVD) of each of the measurement data sets. This decomposition corresponds to a Single Degree of Freedom (SDOF) identification of the measured system for each singular value [31]

The Enhanced Frequency Domain Decomposition technique is an extension to Frequency Domain Decomposition (FDD) technique. This t technique is a simple technique that is extremely basic to use. In this technique, modes are easily picked locating the peaks in Singular Value Decomposition (SVD) plots calculated from the spectral density spectra of the responses. FDD technique is based on using a single frequency line from the Fast Fourier Transform analysis (FFT), the accuracy of the estimated natural frequency based on the FFT resolution and no modal damping is calculated. On the other hand, EFDD technique gives an advanced estimation of both the natural frequencies, the mode shapes and includes the damping ratios [32]. In EFDD technique, the single degree of freedom (SDOF) Power Spectral Density (PSD) function, identified about a peak of resonance, is taken back to the time domain using the Inverse Discrete Fourier Transform (IDFT). The natural frequency is acquired by defining the number of zero crossing as a function of time, and the damping by the logarithmic decrement of the correspondent single degree of freedom (SDOF) normalized auto correlation function [33].

In this study modal parameter identification was implemented by the Enhanced Frequency Domain Decomposition. The relationship between the input and responses in the EFDD technique can be written as, in this method, unknown input is represented with x(t) and measured output is represented with y(t)

$$[G_{yy}(j\omega)]=[H(j\omega)]^{*}[G_{xx}(j\omega)][H(j\omega)]^{T} \quad (1)$$

Where $G_{xx}(j\omega)$ is the r x r Power Spectral Density (PSD) matrix of the input. $G_{yy}(j\omega)$ is the m x m Power Spectral Density (PSD) matrix of the output, $H(j\omega)$ is the m x r Frequency Response Function (FRF) matrix, and * and superscript T denote complex conjugate and transpose, respectively. The FRF can be reduced to a pole/residue form as follows:

$$[H(\omega)]=\frac{[Y(\omega)]}{[X(\omega)]}=\sum_{k=1}^{m}\frac{[R_k]}{j\omega-\lambda_k}+\frac{[R_k]^{*}}{j\omega-\lambda_k^{*}} \quad (2)$$

Where n is the number of modes λ_k is the pole and, R_k is the residue. Then Eq. (1) becomes as:

$$G_{yy}(j\omega)=\sum_{k=1}^{n}\sum_{s=1}^{n}\left[\frac{[R_k]}{j\omega-\lambda_k}+\frac{[R_k]^{*}}{j\omega-\lambda_k^{*}}\right]$$

$$G_{xx}(j\omega)\left[\frac{[R_s]}{j\omega-\lambda_s}+\frac{[R_s]^{*}}{j\omega-\lambda_s^{*}}\right]^{\bar{H}} \quad (3)$$

Where s the singular values, superscript is H denotes complex conjugate and transpose. Multiplying the two partial fraction factors and making use of the Heaviside partial fraction theorem, after some mathematical manipulations, the output PSD can be reduced to a pole/residue form as fallows;

$$[G_{yy}(j\omega)]=\sum_{k=1}^{n}\frac{[A_k]}{j\omega-\lambda_k}+\frac{[A_k]^{*}}{j\omega-\lambda_k^{*}}+\frac{[B_k]}{-j\omega-\lambda_k}+\frac{[B_k]^{*}}{-j\omega-\lambda_k^{*}} \quad (4)$$

Where A_k is the k th residue matrix of the output PSD. In the EFDD identification, the first step is to estimate the PSD matrix. The estimation of the output PSD known at discrete frequencies is then decomposed by taking the SVD (singular value decomposition) of the matrix;

$$G_{yy}(j\omega_i)=U_iS_iU_i^{\bar{H}} \quad (5)$$

Where the matrix $U_i=[u_{i1},u_{i2},\dots,u_{im}]$ is a unitary matrix holding the singular vectors u_{ij} and s_{ij} is a diagonal matrix holding the scalar singular values. The first singular vector u_{ij} is an estimation of the mode shape. PSD function is identified around the peak by comparing the mode shape estimation u_{ij} with the singular vectors for the frequency lines around the peak. From the piece of the SDOF density function obtained around the peak of the PSD, the natural frequency and the damping can be obtained.

RESULTS AND DISCUSSION:

C. Analytical modal analysis of scaled concrete retaining wall:

A finite element model was generated in SAP2000 (1997). Retaining wall was modeled as 3D shell element (in Fig. 2). Structure modeled as an absolutely rigidity shell (thin shell). The selected structure is modeled as a space frame structure with 3D element. Retaining wall was modeled as 3D shell element which has degrees of freedom. At the base of the structure in the model, the ends of every element were fixed against translation and rotation for the 6 degree of freedom (DOF) then creating finite element model of the structure in SAP2000. The following assumptions were taken into account. Scaled concrete retaining wall is modeled using an equivalent thickness and shell elements with isotropic property. All supports are modeled as fully fixed. The members of scaled concrete retaining wall are modeled as rigidly connected together at the intersection points. In modeling of scaled concrete retaining wall the modulus of elasticity E=2.80E10 N/m², Poisson ratio μ=0.2, mass per unit volume ρ=24000 N/m³

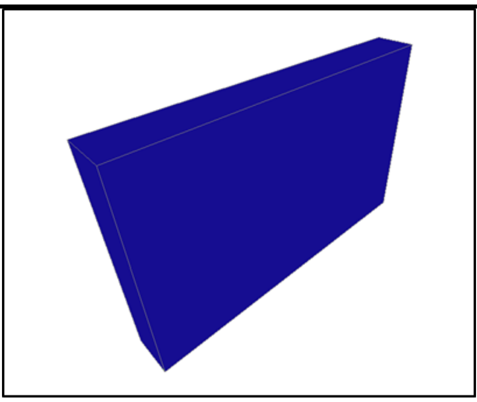
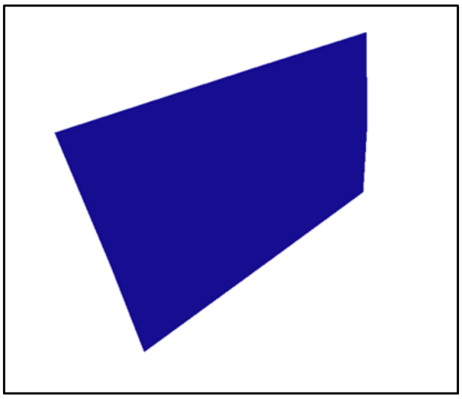


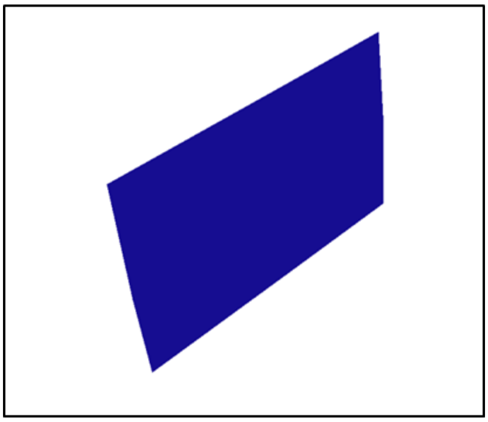
Fig. 2. Finite element model of scaled concrete retaining Wall

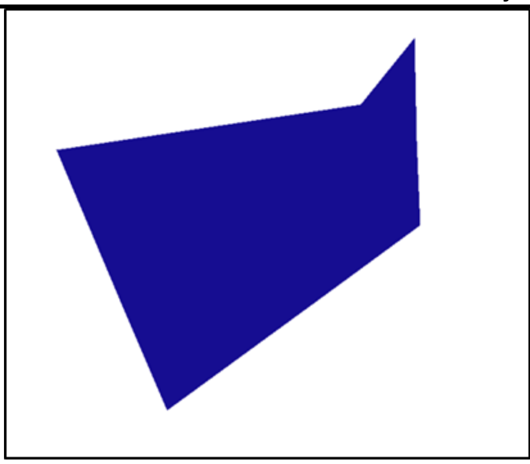
Natural frequencies and vibration modes are concerned a significant impact on the dynamic performance of structures is an important dynamic properties. A total of five natural frequencies of the structure are attained which range between 2 and 9 Hz. The first five vibration mode of the structure is shown in Figure 3. Analytical modal analysis results at the finite element model are shown in Table 2.

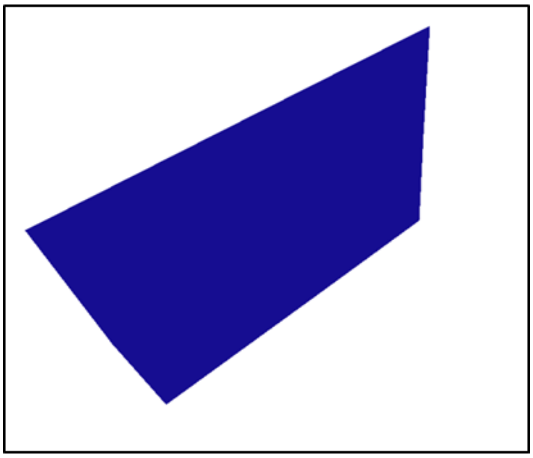
Table 2. Analytical modal analysis result at the first at the Finite Element (FE) model

Mode number	**1**	**2**	**3**	**4**	**5**
Frequency (Hz)	2.20	5.70	6.25	7.75	8.95









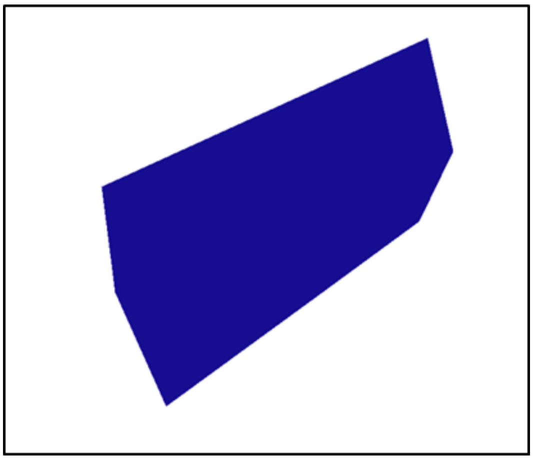


Fig 3. Analytically identified respectively mode shapes of scaled concrete retaining wall

D. Experimental modal analysis of scaled concrete retaining wall:

Ambient excitation was provided by the recorded micro tremor data on ground level. Three accelerometers (with both x and y directional measures) were used for the ambient vibration measurements one of which were allocated as reference sensor always located in the wall (they are shown in Fig. 4). Two accelerometers were used as roving sensors (they are shown in Fig. 4). The response was measured in two data sets (Fig. 4). For two data sets were used 3 and 5 degree of freedom records respectively (Fig. 4). Every data set was measured 100 min. The selected measurement points and directions are shown in Fig. 4. Ambient excitation data from the recorded micro tremor data on ground level given in fig. 5.

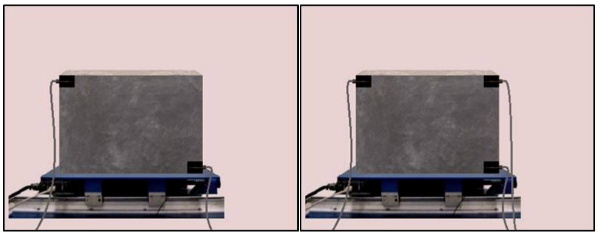


Fig. 4. Accelerometers location of experimental model in the 3D view (first and second setup)

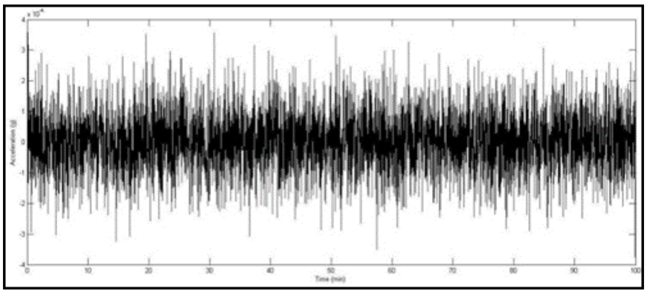


Fig. 5. Ambient excitation data from the recorded micro tremor data on ground level

The data acquisition computer was dedicated to acquiring the ambient vibration records. In between measurements, the data files from the previous setup were transferred to the data analysis computer using a software package. This arrangement allowed data to be collected on the computer while the second, and faster, computer could be used to process the data in site. This approach maintained a good quality control that allowed preliminary analyses of the collected data. If the data showed unexpected signal drifts or unwanted noise or for some unknown reasons, was corrupted, the data set was discarded and the measurements were repeated.

The simple peak-picking method (PPM) finds the eigenfrequencies as the peaks of nonparametric spectrum estimates. This frequency selection procedure becomes a subjective task in case of noisy test data, weakly excited modes and relatively close eigenfrequencies. Also, for damping ratio estimation the related half-power bandwidth method is not reliable at all. Frequency domain algorithms have been the most popular, mainly due to their convenience and operating speed. For modal parameter estimation from the ambient vibration data, the operational modal analysis (OMA) software Artemis extractor (1999) is used. Singular values of spectral density matrices, attained from vibration data using PP (Peak Picking) technique are shown in Figure 6. Natural frequencies acquired from the all measurement setup are given in Table 3.

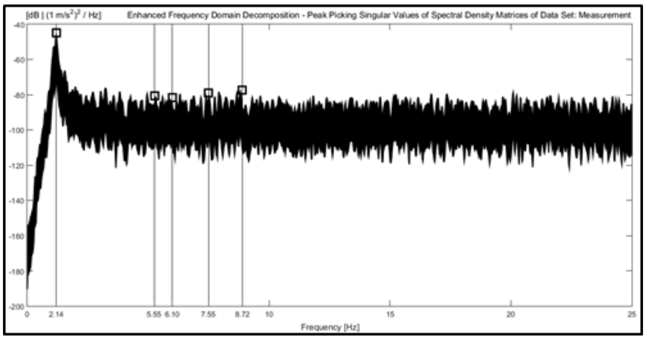
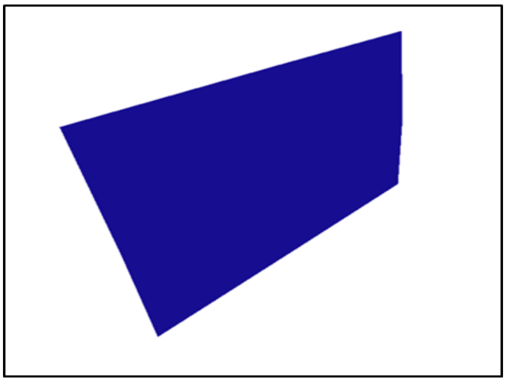


Fig. 6. Singular values of spectral density matrices

Table 3. Experimental modal analysis result at the scaled concrete retaining wall

Mode number	**1**	**2**	**3**	**4**	**5**
Frequency (Hz)	2.14	5.55	6.10	7.55	8.72
Modal damping ratio (ξ)	0.38	0.59	0.62	0.54	0.49

The first five mode shapes extracted from experimental modal analyses are given in Figure 7.



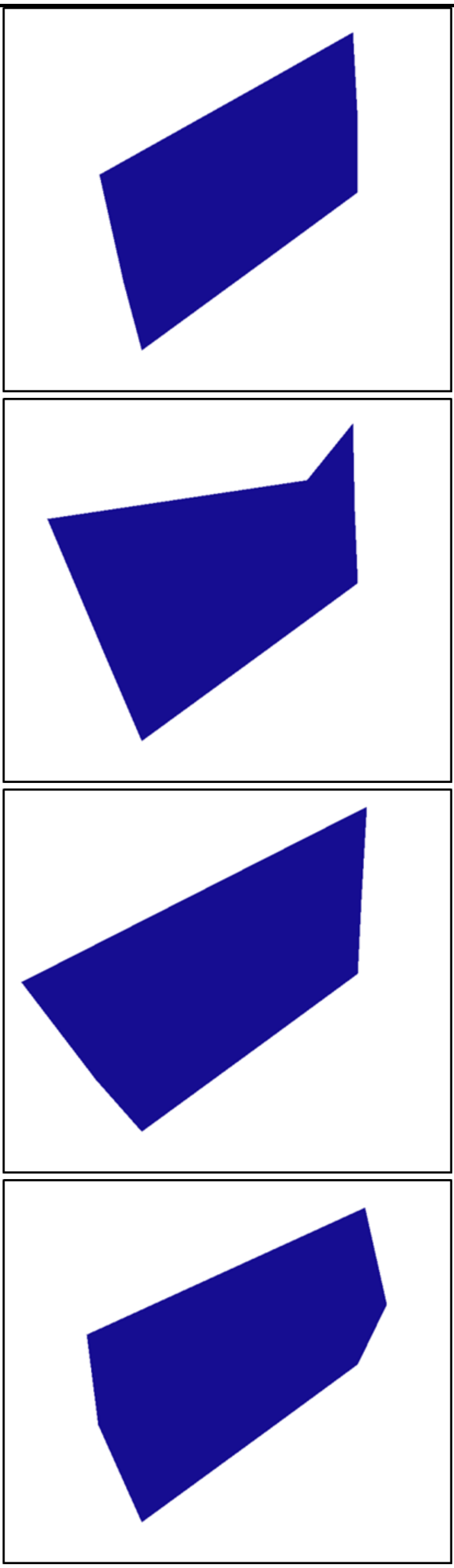


Fig. 7. Experimentally identified respectively mode shapes of scaled concrete retaining wall

E. Comparison of analysis results:

When all measurements are examined, it can be seen that there is best accordance is found between experimental mode shapes. When the analytically and experimentally identified modal parameters are checked with each other, it can be seen that there is a best agreement between the mode shapes in experimental and analytical modal analyses (Table 4).

Table 4. Comparison of analytical and experimental modal analysis results

Mode number	1	2	3	4	5
Analytical frequency (Hz)	2.20	5.70	6.25	7.75	8.95
Experimental frequency (Hz)	2.14	5.55	6.10	7.55	8.72
Difference (%)	2.72	2.63	2.40	2.58	2.57

CONCLUSIONS:

In this paper, analytical and experimental modal analysis of scaled concrete retaining wall was presented. Comparing the result of study, the following observation can be made:

From the finite element model of scaled concrete retaining wall a total of five natural frequencies were attained analytically, which range between 2 and 9 Hz. 3D finite element model of scaled concrete retaining wall is constructed with SAP2000 software and dynamic characteristics are determined analytically. The ambient vibration tests are conducted under provided from ambient vibration data on ground level. Modal parameter identification was implemented by the Enhanced Frequency Domain Decomposition (EFDD) technique. Comparing the result of analytically and experimentally modal analysis, the following observations can be made:

From the finite element model of scaled concrete retaining wall, the first five mode shapes are attained analytically that range between 2 and 9 Hz.

- From the ambient vibration test, the first five natural frequencies are attained experimentally, which range between 2 and 9 Hz.

- When comparing the analytical and experimental results, it is clearly seen that there is very best agreement between mode shapes and frequencies.
- Analytical and experimental modal frequencies differences between 2.40%-2.72%.
- Presented investigation results are shown and confirm of possibility using the recorded micro tremor data on ground level as ambient vibration input excitation data for investigation and application Operational Modal Analysis (OMA) for scaled concrete retaining wall.

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